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1. Theoretical Program on the F Region

J. S. Nisbet, J. Doupnik, D. McCrory, M. Kwei

Work has continued on theoretical and experimental studies of the physics of the F region. Some of the problems that have been receiving particular attention were

1.1 The Seasonal Effect on "Winter Anomaly"

It is generally noticed that in the northern hemisphere peak electron densities are greater during the day in winter than in summer. This effect is of course completely inconclusive of itself because it is well known that the ratio of the atomic oxygen which controls the production rate to the molecular constituents which control the loss rate is extremely altitude dependent and any effect which can cause vertical drifts can cause large changes in the peak density. A study made by Nisbet (1964) showed that these changes interpreted on the basis of an equilibrium layer did in fact appear to correspond to a true difference in the integrated production and integrated loss in the layer. In fact it was shown that even at some stations where the peak densities in summer and winter were comparable, height changes occurred which corresponded to comparable changes in production and loss.

A more striking seasonal effect showed up in the recombination analyses at night by Quinn and Nisbet (1965). It was shown that at Puerto Rico the recombination coefficients calculated by studying the decay of the nighttime F layer became extremely small in winter under low sunspot conditions and showed a marked seasonal effect throughout the solar cycle. These analyses were based on ionosonde records and uncertainties resulted due to lack of information on the profile.

1.2 The Day to Night Anomaly

Current models of the neutral atmosphere show large differences in the ratios of the atomic oxygen to the molecular constituents day to night. When calculations are made of the diffusion coefficient using such models there is a difference of an order of magnitude in the daytime and nighttime values as has been noticed by Rishbeth (1964), Nisbet (1963) and Nisbet and Quinn (1965). The nighttime values measured using current techniques have all been much lower than would be predicted theoretically.

2. Results of Analysis

To investigate these and other problems three series of measurements were conducted at the Aredibo Ionospheric Observatory. The preliminary results of these investigations were presented at the NATO conference in Finse in April. As copies of these papers have been submitted under separate cover only the main conclusions will be summarized here.

2.1 In the daytime F region marked instabilities in the electron temperature and electron density can occur. These instabilities appear as a coupled temperature density fluctuation with a period of the order of an hour. The mechanism of these oscillations is of extreme interest for the study of the morphology of the F region because they can result in differences of the order of one hundred percent in peak electron density between very similar magnetic and solar quiet days. They are of extreme interest in the study of the physics of the region because they may allow estimates to be made of the production loss and diffusion coefficients independently.

which is not possible with equilibrium layers. The mechanism for the fluctuations is also of interest and the manner in which they propagate is being studied. Investigations are being made to examine the extent to which they are coupled to the conjugate ionospheric regions.

2.2 Direct evidence of coupling by photoelectrons was observed in the winter nighttime measurements. Whenever the ionosphere at the conjugate region was illuminated heating was shown to occur at altitudes above 300 km at Arecibo. This effect has later been studied by Carlson (1965) and has been verified from his measurements throughout the year.

2.3 It was shown that there is a production mechanism operating in the nighttime F region in winter. Estimates were made of the magnitude of this effect by a comparison of the dawn production rate, the daytime equilibrium profile and the nighttime profiles. It was shown that a recombination rate of only 1.2×10^{12} electrons/m^2 would be sufficient to explain this result. This was tentatively attributed to the flux of photoelectrons, the extra electron ion pairs produced by photoelectrons, and to the flux of electrons and ions along the field lines due to the difference in the value of nkT at either end.

2.4 Analyses based on summer data at Arecibo using incoherent scatter techniques tend to confirm the values of recombination coefficients measured in summer using the reduced ionograms. The values of diffusion coefficient measured in this way were very low and again in agreement with the ionogram calculations. Because of equipment difficulties the amount of usable summer data was somewhat limited from the 1964 series of measurements and another series was conducted this summer. The results of this series have not yet been completely analyzed.

It was determined that a feedthrough problem has existed in our data and a considerable amount of time was spent reprocessing tape recordings made during the winter 1964 series. The technique used for reducing the tape recorded data appears to have worked well and on subsequent visits to Arecibo it is intended to reprocess such of the summer 1964 data as was tape recorded.

J. Doupnik

A paper written with Dr. Nisbet was presented at the URSI meeting in Washington and at the NATO conference in Norway. It was submitted to J. G. R. and is now being revised with new calculations.

Two weeks were spent at Arecibo making measurements on the equipment and of electron densities and temperatures. Theoretical spectra for a 40 μs pulse were calculated and used to determine the relative power lost by the receiver filters as a function of electron and ion temperature and the ion mass.

An error in the radar range of backscattering equation was discovered and the electron density profiles and dependent calculations are being reprocessed.

D. McCrory

A joint paper by Dr. Nisbet and myself was given at the Spring URSI meeting. The paper was entitled "Recombination in the Nighttime F-Region from Incoherent Scatter Measurements".

A preliminary write-up of my thesis was begun using data obtained in the summer and winter of 1964 at Arecibo, Puerto Rico. A literature search was also undertaken with emphasis placed on the ionospheric F-layer and the scattering of radio waves by ionized gases.

One week was spent at Wallops Island in support of the Mother-Daughter rocket firing.

The last three weeks in June were spent at Arecibo, Puerto Rico collecting data for my thesis.

3. Mother-Daughter Rocket Program

J. S. Nisbet

3.1 Propagation Experiment

Two flights of the mother-daughter rocket experiment have been made to date. In the first on 13th January a separation failure of the mother-daughter payload assembly marred an otherwise successful launch. The separation mechanism was modified on the basis of a thorough analysis of the design and a second and successful flight was obtained on May 19th. The analysis of the results of this experiment have not been completed but our work to date indicates that high quality data throughout the flight was obtained on the mother-daughter system. The probe experiment on the rocket showed a rocket potential of about -2 volts. While final trajectory information is not yet available it appears likely that the comparison of the probe and propagation measurements will be of considerable interest. Simultaneous measurements at Arecibo, Millstone Hill and Prince Albert were made during this flight in addition to observations by a network of ionosonde stations.

The remaining two flights of the current series are planned for Wallops Island on October 5, 1965. It is planned to launch two rockets on one night when the ionosphere along the flight path is in darkness. For one firing the conjugate ionosphere will also be in darkness but for the other the conjugate ionosphere will be illuminated. The electron temperature probe will be modified for this flight to increase considerably both the range of sweep voltages and the sensitivity. In this way it is hoped that the spectrum of the incident photoelectrons can be obtained for comparison with the effects observed in the electron density profiles.

J. Widmaier

The beginning of this past report period was mainly devoted toward the preparations and data reduction of the January 13th flight; this included a correction to our magnetometer and Doppler data using the finalized form of the trajectory.

The preflight preparation for the May 19th flight included skeleton graphs and calculations to convert raw data at the launch site to a quick approximation of final results. 6 and 12 mc phase graphs for data reduction were the main items of interest. For data reduction curves of phase/separation distance versus electron density with θ (angle of propagation w. r. t.field) as a parameter were completed. Useful graphs of how N^2 (index of refraction) varies with $X(f_n^2/f^2)$ for each 6 and 12 mc waves were obtained using methods described by Budden.

Analysis of preflight testing and checkout data were made. Two days were spent at Goddard Spaceflight Center while the payload underwent vibration and telemetry checks; minor difficulties were corrected. Then in May a week was spent at Wallops Island for the preflight checks which included calibration of the individual experiments, transmitter and receiver checks, etc.

Analysis of the raw data from the 8. 29 flight is well underway. The magnetometer data is completed; only the finalized trajectory is needed to complete the analysis. Separation velocity was determined to be 5. 34 m/sec. Singal strengths of the three separating frequencies were analyzed throughout the flight and the data showed a dropout in the 73 mc signal strength shortly after M-D separation. This was thought to cause the irregular effects in the phase data but recent tests at Spacecraft showed that the phase comparator which, using the 73 mc as a reference, was able to function even at the -100 dbm level which occurred throughout the major portion of the flight. All temperature data from the M-D compartments has been analyzed; results show that within the instrument compartments, the temperature rose only a few degrees throughout the flight.

Complications due to the motion of the payload and dropout in the 73 mc signal strength slowed the data reduction down. Recently I have obtained a very reasonable density profile for the upleg of the flight. From the 12 mc phase data which started at 280 km and ended at 546 km a reasonable profile was obtained. A 20 second overlap of 6 and 12 mc phase data started at 200 and thus the density profile was continued to the peak at 950 km. The downleg 6 mc phase data is yielding very reasonable results and density profile shows a close overlap with the profiles from the upleg. Only the finalized form of the trajectory is needed to complete our first order approximation to the profiles. Second order corrections of temperature vs agc and phase will be included shortly.

3.2 M-D Probe Experiments
L. C. Hale

Two of the probe assemblies have been launched from Wallops Island on Argo D-4 rockets.

During the first launching, in January, the probe experiment functioned normally, but no useful data was received because of the failure of M-D separation. A rather serious case of radio frequency interference developed during the launch operations. Between the first and second launching a filtering system was developed which eliminated this difficulty.

The second launch, on May 19, was successful and apparently gave good ion data on ascent and descent, and will thus permit determination of ion density and temperature. A rather high negative potential of about 2 volts was acquired by the payload, which prevented the observation of electrons by the experiment.

The next experiment is being modified to yield a much greater sensitivity to electrons, and should be capable of examining the "hot" electron energy spectrum.

D. Hoffman

Theoretical studies were made to determine the output waveforms of the derivative channel. The results were plotted for various values of the RC time constant of the differentiator.

The ion probe was flown on a Javelin rocket on May 19 and a trip was made to Wallops Island, Virginia in preparation for this flight.

The data is being reduced and ion density profiles, ion temperatures, and vehicle potentials will be obtained; the final results cannot be obtained until digital information on the flight trajectory is available. Preliminary results indicate that the measured ion densities are low by approximately a factor of four at the lower altitudes. The measured vehicle potential will be about -2.0 volts.

4. F Region Theory

C. Comstock

A talk was prepared and given at the Spring URSI meeting on "A Three Fluid Model Ionosphere". A paper was made out of this talk and has been submitted to JATP for publication.

An attempt was made to obtain an analytic solution to the time-varying behavior of a simple model of the F-layer, using an equation similar to that of Nisbet in Scientific Report 194. The method used the LaPlace Transform. Unfortunately the resultant transformed equation I was unable to solve. The solution depends critically on the ionosphere flux, due to the ionization and recombination, through the boundaries. But this is an unsolved question. In addition, even if this were known, solutions would be obtainable only for very large, and very small values of the transform parameter k. Using Tauberian theorems, the short time, and long time, solutions respectively could be obtained. One can infer from the nature of the general solution to the transformed equation for large k that the short time behavior of the

F-layer appears to depend on the variable x/t and is basically some combinations of Hankel functions of imaginary argument, where $x = e^{-z}$. However, more detailed results are not available.

Entered into correspondence with D. C. Carpenter at Stanford concerning the electron distribution in the exosphere and the reasons for the sudden discontinuity in the electron density profile at about 4 earth radii.

5. Aerodynamic Theory

D. P. Hoult

The work on the aerochemistry of supersonic D region probes was summarized in an article "Weak Shock Waves in the Ionosphere", which appeared in the J.G.R. Vol. 69, No. 21.

Analysis was carried out for supersonic probes with sharp nose cones, such that the shock generated was a weak shock. Up to about 90 km, the problem was still amenable to continuum approach.

In the article, an analytical expression was obtained to account for the effects of weak shocks on the measured ion concentration. The result was compared with an equilibrium calculation, which was shown to be far too pessimistic. The effects of impurities were also discussed.

The essential chemical reactions were discussed in the analysis. The total percentage change of any species was shown to be the sum of the change due to density jump and the change due to finite rate reactions. Examination of the orders of magnitude of the reaction rates times with the appropriate number densities led to the conclusion that the percentage changes of $n(A_2^+)$ were caused only by the density jump across the shock. However, the percentage changes of $n(A_2^-)$ and n(e) due to chemical reactions could not be ignored at lower altitudes.

A typical computation was carried out for a Mach 2 probe. Equilibrium calculation gave a $n(A_2^+)$ percentage change of 70, while the weak shock wave yielded only 0.50. At 50 km, for $n(A_2^-)$, the chemical reaction added another 0.12 at 10 cm behind the shock to make it a 0.62 total percentage increase. Above 70 km, due to the exponential decrease in the number of molecules, the reaction contribution was negligible.

It was also shown that in the presence of sodium, owing to the exponential dependence of K on temperature, the percentage change in K was of order ten. Hence the effects of impurities could raise the errors introduced by an order of magnitude.

Work will continue on this problem and other problems originating in the interpretation of the probe measurements when in the vicinity of the mother assembly.

During the last three months, calculations on compressibility effects on D-region probes have been pursued. It is hoped that these calculations will be soon complete. A paper "Alfven Waves in an Incompressible Media" was written which gives an amplification process for the magnetic field in a sunspot. Two papers were accepted by Physics of Fluids, "The Effect of a Magnetic Field on the Stability of Jet or Wake" and "The Helical Motion of a Sphere in a Magnetic Field".

Experimental studies of the statistical properties of high altitude turbulence as derived from electron density measurements, made at Arecibo, was pursued. These studies are still preliminary.

Two papers were published, "The Round Laminar Jet in an Axial Magnetic Field", Phys. Fluids May 1965 and "D Region Probe Theory", Journal of Geophys. Res. July 1965.

5. Langmuir Probe Theory

D. P. Hoult, L. C. Hale and T. J. Kuo

The problem area covers the essential physics of the operation of probes for the measurement of the number densities of charged particles in the D region. The significance of such an experiment is first, that positive and negative ions are not observable by ground based techniques, and second, the experimental determination of the number densities of positive ions, negative ions, and electrons is a necessary first step in understanding the complex chemical structure of the D region.

To avoid shock wave effects, planar probes with parachutes were launched into the D region and the current to a known area of the nose was measured. The parachute slowed down the velocity of probe to 100 m/sec, which was about 0.3 Mach number. Since the variation in mobility and diffusivity, and the effects of chemical reactions are all O (Mach number)^2, the first order approximation of this problem is an incompressible flow. The work done on the first approximation was summarized in an article "D Region Probe Theory", which appeared in the July issue of the J.G.R.

The article gives analytical relationships between positive ion, negative ion and electron densities and the current to the probe and the probe voltage, which are essential for measurement interpretation. These relationships are formally analogous to Gerdien condenser theory.

Due to the small concentration of charged particles in the flow, the fluid mechanical motion can be tackled independent of the motion of the charged particles. This uncoupling greatly simplifies the problem. Also the electric potential about the probe can be uncoupled from the charge distribution, rendering the vacuum field simplification. This is due to the very low number density of charged particles ($\alpha \sim O(1)$) and the high wall potential ($\phi_w >> 1$).

It is then shown that, for a negatively charged probe, the region where positive ion diffusion is important is very much thinner than the laminar boundary layer. Hence the positive ion current depends only on the electric field at the probe surface. The effects of convection occur principally in determining the negative ion current to a negative probe, as is explicitly worked out for the case of a disc.

It is also shown that, for a positive probe, the electron current completely dominates all other effects. Thus it is impossible to measure negative ion densities with a positive probe.

For a sample calculation, the flow over a charged disc of a fixed voltage is considered. The relationship between voltage, number densities and current to a small area at the center of the disc is established. In this special case, it is shown that the negative ion current to a negative disc is very small compared to the positive ion current.

Besides the work done on the incompressible approximation, the effects of compressibility are now being under study.

6. Mass Spectrometry

B. R. F. Kendall

Most of the work carried out during this report period was concerned with the Vacuum Chamber mentioned in the previous report. The chamber is intended to provide a simulated space environment for tests on experimental mass spectrometers. Large components were constructed by outside contractors, with considerable work on smaller items being done by the Electrical Engineering, Engineering and Physics machine shops.

The high-vacuum chamber is now being used routinely, with only occasional interruption for servicing or for connection of accessories. A gas inlet system, absolute pressure gauge, bell-jar hoist, and a set of oil migration baffles have been designed, built and installed. Modifications to the time-of-flight mass spectrometer used as a gas composition monitor are being made in order to improve its performance and provide more working space in the chamber.

A bakeout oven, a pulse amplifier and an electron multiplier power supply have been built and tested with satisfactory results. An ion pump power supply has also been constructed. These units are needed for use with various types of pulsed non-magnetic mass analyzers which are at present in the early stages of development.

Work has been revived on the Adsorption Trap project and a model is being built. The project is based on an earlier theoretical study of the properties of adsorbent-lined vacuum manifolds. It is expected that the results will be applicable to space simulation problems.

Measurements of the equilibrium gas pressures and gas compositions in the presence of thermo-electrically cooled artificial zeolite were made. The zeolite acted as a pump for H_2O, CO_2 and hydrocarbons and simultaneously as a source for N_2 and O_2. Because a mechanical vacuum pump has exactly opposite characteristics (pumping N_2 and O_2 while either releasing or not pumping the other gases) the combination of the two procedures may offer a simple method of simulating pressures corresponding to altitudes of up to about 125 km. Work is continuing on an improved system of this type.

An electron beam switching tube was designed, built and tested as a special project by an undergraduate working under supervision. It is hoped that it will be useful for time-scan conversion and data processing work in the laboratory.

Theoretical analyses were carried out on two types of convolution transform generators which appear to have practical possibilities.

An absolute pressure gauge based on the Brownian motion of small particles has also been studied theoretically. Recent developments in electrostatic suspension make the approach appear promising.

Three research students are now working towards their Master's degrees in the laboratory.

7. Paper Publications, etc.

The following papers have been published:

"On Wave Propagation in a Random Medium" by Craig Comstock. Published in J.G.R., Vol. 70, No. 9, 2263-2264, May 1, 1965.

"D-Region Probe Theory" by David P. Hoult. Published in J.G.R. Vol. 70, No. 13, 3183-3187, July 1, 1965.

The following papers were accepted for publication:

"Electron Temperature and Density Fluctuation in the Daytime Ionosphere" by J. S. Nisbet and J. Doupnik, J. Geophys. Res.

"Simple, Stable, and Reliable Transistorized D.C. Amplifiers" by L. C. Hale, J. S. Nisbet and C. K. Wilk, I.E.E.E. Trans. on Instrumentation and Measurement.

The following Scientific Reports have been issued:

No. 242. "An Application of Sampling Theory to the Reduction of Ionograms" by R. Vest, June 1, 1965.

No. 246. "Least Squares Reduction of Bottomside Ionograms" by J. M. Grebowsky, August 15, 1965.

The following papers were presented at scientific meetings:

"A Three-Fluid Ionospheric Model" by Craig Comstock. Presented at the AGU-URSI-IEEE Meeting in Washington, D.C., April 19-23, 1965.

"Application of Least Squares to the Reduction of Bottomside Ionograms" by J. M. Grebowsky. Presented at the AGU-URSI-IEEE Meeting in Washington, D.C., April 19-23, 1965.

"Preliminary Measurement and Error Analysis of D-Region, Rocket Ion Density Measurements" by D. P. Hoult, L. C. Hale and R. G. Willis. Presented at the AGU-URSI-IEEE Meeting in Washington, D.C., April 19-23, 1965.

"Determination of Optimum Frequencies for Ionogram Sampling Points Yielding Parameters of Monotonic Layers" by R. Vest. Presented at the AGU-URSI-IEEE Meeting in Washington, D.C., April 19-23, 1965.

"Recombination in the Nighttime F Region from Incoherent Scatter Measurements" by J. S. Nisbet and D. McCrory. Presented at the AGU-URSI-IEEE Meeting in Washington, D.C., April 19-23, 1965.

"Electron Temperature and Density Fluctuations in the Daytime Ionosphere" by J. R. Doupnik and J. S. Nisbet. Presented at the AGU-URSI-IEEE Meeting in Washington, D. C., April 19-23, 1965.

"Electron Densities and Temperatures in the F-Region from Back-scatter Measurements at Arecibo" by H. C. Carlson and J. S. Nisbet. Presented at the AGU-URSI-IEEE Meeting in Washington, D. C., April 19-23, 1965.

"Electron Density and Collision Frequency Measurements of the D-Region with Radio Wave Phase and Amplitude Interaction" by A. J. Ferraro and H. S. Lee. Presented by A. H. Waynick at the NATO Advanced Study Institute on "Electron Density Profiles in the Ionosphere and Exosphere", Finse, Norway, April 21-31, 1965.

"Preliminary Results of Rocket Measurements of D-Region Ion Densities" by L. C. Hale, D. P. Hoult and R. G. Willis. Presented by A. H. Waynick at the NATO Advanced Study Institute on "Electron Density Profiles in the Ionosphere and Exosphere", Finse, Norway, April 21-31, 1965.

"Recombination in the Nighttime F-Region from Incoherent Scatter Measurements" by J. S. Nisbet and D. McCrory. Presented by A. H. Waynick at the NATO Advanced Study Institute on "Electron Density Profiles in the Ionosphere and Exosphere", Finse, Norway, April 21-23, 1965.

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8. Personnel

Nisbet, J. S. Ph. D. Penn State 1960	Part-time	Assoc. Prof. E. E.
Hoult, D. P. Ph. D. Cal. Tech. 1962	Part-time	Asst. Prof. Aero
Kendall, B. R. F. Ph. D. U. of Western Aust. 1960	Part-time	Assoc. Prof. Phys.